Childhood Exposure to Magnetic Fields: Residential Area Measurements Compared to Personal Dosimetry

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We examined the relation between area measurements of residential magnetic fields and personal dosimetry measurements among 64 control children age 2–14 years from the National Cancer Institute-Children's Cancer Group's nine-state case-control study of childhood leukemia. During a typical weekday, an activity diary was completed, and a 24-hour measurement was obtained in each child's bedroom. According to the activity diaries, children spent more than 40% of the 24 hours in their bedrooms, and 68% of their time at home. We found that at-home personal dosimetry levels were highly correlated with total personal dosimetry levels in children under 9 years (Spearman correlation coefficient, $R = 0.94$), whereas the correlation was lower in older children ($R = 0.59$). For all children combined, bedroom 24-hour measurements correlated well with at-home personal dosimetry levels ($R = 0.76$). The 24-hour bedroom measurement was a useful predictor of both at-home and total personal dosimetry measurements. Particularly for younger children, our data suggest that in-home area measurements predict both current residential and current total magnetic field exposures. This information will be valuable for assessing the validity of exposure assessment in previous and ongoing studies and for developing measurement protocols for future studies. (Epidemiology 1996;7:151–155)

Keywords: electromagnetic fields, environmental monitoring, epidemiologic measurements, data collection, children.

An ongoing collaborative National Cancer Institute-Children's Cancer Group (NCI-CCG) case-control study is evaluating the relation between magnetic field exposures and the occurrence of childhood acute lymphoblastic leukemia among children under age 15 years. The measurement protocol is based on a detailed dosimetry study of 29 volunteer children. The Washington DC study[1] showed that the most variable component of children's exposure to power-frequency magnetic fields was in residential rather than nonresidential settings and that residential area measurements were an excellent predictor of total exposures. Area measurements made in each child's bedroom, where children spent an average of 44% of a 24-hour weekday, were more highly correlated with the child's personal residential exposure than measurements made in other parts of the house. The purpose of the present investigation was to evaluate the validity of these findings among controls in the NCI-CCG study population, which includes children age 0–14 years from nine midwestern and Mid-Atlantic states, selected by random digit dialing and age matched to cases.

Participants and Methods

Study Population

We reviewed all control children enrolled in the NCI-CCG case-control study after October 1991 for possible inclusion in the present dosimetry study. We considered children to be eligible for this study if: (1) they had lived in their current residence long enough to be eligible for magnetic field measurements according to the overall study protocol, (2) they were less than 15 years of age at the time of the residential visit, (3) they agreed to wear the personal dosimeter during the entire 24-hour period, except when sleeping, and (4) they and their parents were willing to complete a detailed 24-hour activity diary. To control study costs, only children residing within a 1-hour drive of any of the seven data collectors' homes were enrolled in the dosimetry study. Our target sample size was 60, with approximately half of the children less than age 9 years and half age 9 years or older.

Procedures and Instruments

Data were collected only on weekdays when children were following their usual schedule (for example, attending school or day care). Personal dosimetry and area measurements were obtained for the same 24-hour period. The study was conducted over the course of 2 academic years.

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Submitted October 21, 1994; final version accepted August 25, 1995.

In the absence of compelling evidence favoring an alternative exposure metric, we, like previous epidemiologic investigators,[2–6] focused on the average level of exposure to magnetic fields. We used two types of meters in this study, one to collect personal dosimetry data and one to take area measurements in the child's home. The Amex-3D meters, described in detail elsewhere,[7] directly measure the cumulative magnetic field in the bandwidth from 25 to 1,200 Hz and were used to collect personal exposure data.

After carefully instructing both parent and child, the data collector gave two Amex-3D meters to the subject's parent, one to be activated and used only while the subject was inside the home or immediately outside in the yard, and the second to be activated and worn by the subject only while away from home. Each meter was placed in a childproof pouch worn on a belt or in a backpack. While the child slept, the activated at-home meter was placed near the child's bed, at least 3 feet from any electrical appliances, and where the magnetic field was within 20% of the reading on the child's bed.

Parents and children kept an activity diary to record the child's whereabouts for each 15-minute interval. The data collector retrieved the meters and the diary at the end of the 24-hour period.

We used EmdexC meters (Electric Field Measurements Company, West Stockbridge, MA)[8,9] to take 24-hour area measurements in the home. The EmdexC meters measure separately the three vector components of magnetic flux density in a bandwidth extending from 40 to 400 Hz. The EmdexC meter, which was programmed to record spot measurements every 30 seconds, was placed under the child's bed, if possible. Otherwise, it was placed at a location that had a meter reading within 20% of a reading taken on the bed, and 3 feet from any electrical appliance. After recording 2,880 spot measurements during the 24-hour period, the meter was programmed to turn off automatically.

The data collector also obtained spot measurements in the subject's bedroom, the family room, the kitchen, and immediately outside the front door, using the EmdexC meters. We present only the average of the 24-hour bedroom measurements, since children spent most of their at-home time in their bedrooms, and since this measurement was more closely correlated with at-home personal exposure than measurements made in other rooms in the house.

Statistical Analysis

Since the distributions of the 24-hour and personal dosimetry measurements were skewed, we used the median to denote the central tendency, and the interquartile range (the 75th percentile value minus the 25th percentile value) as the corresponding measure of variability. We calculated Spearman rank order correlation coefficients (R) to assess the relations between the total personal dosimetry measurement and its components, the at-home and away-from-home personal dosimetry measurements. We also compared magnetic field levels from the personal dosimeters with the 24-hour bedroom measurements. We conducted regression analyses to determine whether the 24-hour bedroom measurement could be used to predict the average at-home and total exposure of children based on personal dosimetry values. We regressed the log-transformed at-home and total personal dosimetry averages on the log-transformed 24-hour measurement taken in the child's bedroom to determine the proportion of variability in the personal dosimetry data that could be explained by the 24-hour area measurement.

TABLE 1. Median Percentage* of Time Children Spent in Various Locations on a Typical Weekday, NCI-CCG 1993 Nine-State Study

	Age		
	<9 Years (N = 33)	≥9 Years (N = 31)	All Ages (N = 64)
At home	76.0	61.1	67.9
In bedroom	43.1	39.6	41.7
In family room	16.0	8.3	10.4
In kitchen	3.5	2.1	2.2
In other rooms	12.5	8.3	10.4
Away from home	24.0	38.9	32.1
At school/day care	9.4	27.1	22.9
Other	8.3	9.7	8.9

* The sum of the medians is not generally equal to the median of the sum.

Results

Of 83 eligible children, 17 did not wish to participate, owing to the demanding protocol, and we excluded two because they became ill during the 24-hour data collection period. The final sample consisted of 39 boys (19 under age 9 years and 20 age 9 years or older) and 25 girls (14 under age 9 years and 11 age 9 years or older). The children's ages ranged from 2.5 to 14.6 years, with a median of 8.6 years. Among children under age 9 years, the median age was 5.1 years.

The activity diaries revealed that the median time spent at home exceeded two-thirds of the 24-hour study period (Table 1). As expected, younger children spent more time at home than older children (a median of 18.2 hours *vs* 14.7 hours), and less time in school/day care (a median of 2.3 hours *vs* 6.5 hours). For all ages combined, the median amounts of time spent in various rooms were: 10 hours in the child's bedroom, 2.5 hours in the family room, and 0.5 hour in the kitchen.

At-home personal exposure levels were more variable in younger children than in older children, whereas away-from-home personal exposure levels and variability were similar for younger and older children (Table 2). The distributions of the 24-hour bedroom area measurements were similar for younger and older children.

The Spearman rank correlation between at-home personal exposure and total exposure (at-home plus away-from-home) varied with age, with a very strong correlation observed among younger children (R = 0.94), and moderate correlation among older children (R = 0.59). Away-from-home exposure was only weakly correlated

TABLE 2. Medians, 25th and 75th Percentiles, and Interquartile Ranges of Time-Weighted Average Personal Dosimetry Measurements and 24-Hour Bedroom Measurements (in Microtesla), NCI-CCG 1993 Nine-State Dosimetry Study

	Age		
	<9 Years (N = 33)	≥9 Years (N = 31)	All Ages (N = 64)
Personal: at home			
25th percentile	0.064	0.049	0.054
50th percentile	0.111	0.085	0.095
75th percentile	0.172	0.126	0.167
Interquartile range*	0.108	0.077	0.113
Personal: away from home			
25th percentile	0.044	0.048	0.048
50th percentile	0.084	0.087	0.087
75th percentile	0.118	0.126	0.125
Interquartile range	0.074	0.078	0.077
Personal: total			
25th percentile	0.072	0.072	0.072
50th percentile	0.113	0.102	0.107
75th percentile	0.167	0.181	0.180
Interquartile range	0.095	0.109	0.108
Bedroom, 24-hour			
25th percentile	0.051	0.037	0.048
50th percentile	0.089	0.083	0.086
75th percentile	0.143	0.122	0.139
Interquartile range*	0.092	0.085	0.091

* Interquartile range = the 75th percentile value minus the 25th percentile value.

with total exposure in younger children (R = 0.16), whereas a moderate correlation was seen for older children (R = 0.65). At-home exposure was not correlated with away-from-home exposure in either age group ($|R| < 0.02$ for both age groups).

There was good correlation between the 24-hour bedroom measurements and at-home personal dosimetry levels (R = 0.76 for younger children and R = 0.72 for older children). In younger children, the correlation between the 24-hour bedroom measurement and total personal dosimetry level was 0.75; in older children, it was 0.41. In Figure 1, we show a scatterplot of the log-transformed personal dosimetry data (total exposure, at-home plus away-from-home) *vs* the log-transformed 24-hour bedroom measurements.

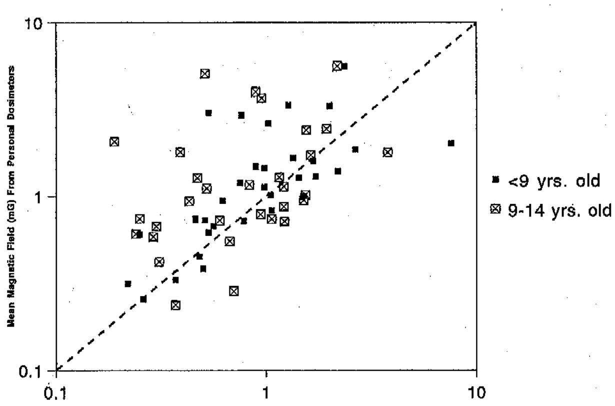

FIGURE 1. Total magnetic field from in-home and away-from-home personal dosimeters *vs* magnetic field from 24-hour stationary meter placed in the child's bedroom.

Regression analysis of the personal dosimetry data revealed that the 24-hour bedroom measurement accounted for 51% of the variability in the at-home personal exposure values in children under age 9 years, and 47% of the variability in children age 9–14 years. The 24-hour bedroom measurement explained 49% and 14% of the variability in total personal exposure in younger and older children, respectively.

Discussion

Table 3 compares the methods and results of this study with those of previous studies.[1,10] The methods used in the Washington DC study were similar to those of this study, except that only children under age 9 years were included in that study. The Geomet study[10] differed from both the current study and the Washington DC study in that the subjects were chosen based on potential for exposure by assessment of wire codes in specific neighborhoods. All three studies found that children spent over 60% of their time during a typical weekday at home and that approximately 40–45% of the 24-hour period was spent in the child's bedroom. Young children in the NCI-CCG study spent a smaller proportion of time in school or day care compared with the Washington DC area children (9.4% *vs* 19.2%). Generally, the magnetic field levels in all three studies were quite similar in magnitude and variability, although the somewhat higher levels in the Geomet study probably reflect the exposure-based sample selection. All three studies found a high correlation between area measurements taken in the child's bedroom and at-home personal dosimetry levels, in both younger and older children. Strong correlations were also found for younger children between the total personal dosimetry levels and the 24-hour bedroom measurements, whereas this correlation was only moderate (R = 0.41) for older children in the NCI-CCG study.

The actual correlation between at-home and total exposure in older children may be stronger than that seen in this study, since activity patterns and magnetic fields were measured on schooldays only, and weekends, holidays, and summer vacation were ignored. School-age children spend only about one-eighth of their time in an entire year at school, assuming approximately 180 six-hour schooldays. Although time spent in school is exceeded only by time spent in residence, the costs and efforts involved in obtaining exposure data for this fraction of time may be extensive, and obtaining accurate data may be problematic. In Massachusetts and California,[11] personal dosimetry and area measurements were made for 35 subjects ages 0 to 18 years, and school spot measurements were not found to predict school personal dosimetry levels. In Washington DC,[1] we experienced extensive difficulties in obtaining access to schools and day care centers. In the Geomet study,[10] the local board of education would not permit in-school measurements. The problems of historical assessment would be com-

TABLE 3. Comparison of NCI-CCG Personal Dosimetry Study with Previous Studies

	NCI-CCG	DC Pilot Study	Geomet Study
Study attributes			
Number of subjects	64	29	28
Geographic location	9 midwestern states	Washington DC	Frederick, MD
Age of subjects	2–14	0–8	<4, 8–11
Sample selection	Random digit dialing	Volunteers	Volunteers, stratified within neighborhoods by potential for exposure
Children's activity patterns			
Mean % time spent in the home			
Younger children*	78	71	81
Older children†	62		62
Mean % time spent in the bedroom‡			
Younger children*	40	44	51
Older children†	41		40
Electromagnetic field measurements (μT)§			
Mean/median in-home Amex-3D	0.10	0.14	0.19
SD/interquartile range	0.11	0.14	0.13
Mean/median away-from-home Amex-3D	0.09	0.11	0.18
SD/interquartile range	0.08	0.04	0.14
Mean/median total Amex-3D	0.11	0.13	0.19
SD/interquartile range	0.11	0.11	0.10
24-hour bedroom EmdexC	0.09	0.13	
SD/interquartile range	0.09	0.11	
Correlations between measurements			
In-home Amex-3D and 24-hour bedroom			
Younger children	0.76	0.83	0.69
Older children	0.72		0.98
In-home Amex-3D and total Amex-3D			
Younger children	0.94	0.96	
Older children	0.59		
Total Amex-3D and 24-hour bedroom			
Younger children	0.75	0.86	0.71
Older children	0.41		0.92

* Defined as <9 years for NCI-CCG and Washington DC studies, <4 years for Geomet study.
† Defined as 9–14 years for NCI-CCG study, 8–11 years for Geomet study.
‡ For Geomet study, % time spent in bed.
§ Means (standard deviations, SD) are presented for the Washington DC and Geomet studies, medians (interquartile range) for the NCI-CCG study. For the Geomet study, results are presented for children <4 years.

pounded in older children, since each child may have attended several schools and used several classrooms within each school.

Our study found reasonably good concordance between measurements of magnetic fields from personal dosimeters and area measurements taken in the bedroom, especially in children under age 9 years. Our results suggest that exposure misclassification is more likely to occur in older children than in younger ones when total magnetic field exposure is estimated solely from residential measurements. If magnetic field exposure is associated with cancer, age-specific analyses may be appropriate since relative risk estimates may be attenuated more strongly in the older age group. We do not expect age-related misclassification to have a major impact in our ongoing case-control study, however, since only 16% of the population in the overall NCI-CCG study is age 9 years and older.

Strengths of this study include selection of participants by random digit dialing, in contrast to the volunteer populations used in other studies.[1,10,11] Despite the demanding nature of the protocol, a high participation rate (80%) was achieved. Limitations of the study include the fact that data collection was limited to a single 24-hour period; however, the 24 hours were chosen to be a typical school or day care day. Also, activity diary data were not validated, owing to logistic and financial constraints. Lastly, our study does not address the question of whether current residential exposure is an accurate reflection of historical exposure.

Exposure assessment remains a major difficulty in epidemiologic studies of magnetic field effects, in part because of the lack of an identified carcinogenic mechanism for magnetic field exposure. Some investigators have postulated that alternative metrics, such as peak exposures, the proportion of time above a certain field level, abrupt changes in field density, or high-frequency transients are more likely to be important than time-weighted averages. Many of these proposed "metrics," however, are strongly correlated with simple average measures.[12,13] The most appropriate temporal window for exposure is currently unknown, but since laboratory studies indicate that magnetic fields are not genotoxic and are more likely to act as promoters,[14,15] recent exposure is more likely to be relevant than distant exposure. Exposure assessment may be complicated by temporal variability due to fluctuations in power line and grounding system current flow,[10,11,16] time-dependent variability in personal activity patterns,[10,14,17] and the effects of localized fields from in-home wiring and appliances.[10,11,16,18] Additional problems may result from limitations of the meters,[11] meter malfunctions, and errors in calibration.

Although personal dosimetry may play a critical role in certain methodologic studies, its value for exposure assessment in case-control studies is limited. Serious illness is likely to alter the behavior and exposure patterns of the cases, which might result in etiologically irrelevant case-control differences in exposure measurements taken subsequent to diagnosis. Additionally, age-related changes in activity among children may result in altered exposure patterns. Thus, contemporary personal dosimetry data are unlikely to provide valid exposure estimates for the etiologically relevant time period.

This detailed personal dosimetry study of children under age 15 years indicates that area measurements provide a useful surrogate for at-home personal exposure to magnetic fields in all children, and for total magnetic field exposure in young children. Studies of temporal variability[10,11,16,17] suggest that improved ability to predict total exposure levels may be more likely to result from replication of in-home measurements than from assessment of nonresidential exposures. Our results will be valuable for developing measurement protocols for future studies, and for evaluating the validity of exposure assessment in previous and ongoing case-control studies of childhood cancer and magnetic field exposure, all of which have utilized only residential measures of magnetic field exposure. In the NCI-CCG case-control study, 84% of the study population is under 9 years of age, and in this age group, residential area measurements appear to provide useful surrogates for total personal exposure.

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